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The Airbag as a Supplement to Standard Restraint Systems in the AH-1 and AH-64 Attack Helicopters and Its Role in Reducing Head Strikes of the Copilot/Gunner

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Accident investigation records of U.S. Army helicopter crashes show injuries of pilots due to striking a structure inside the cockpit outnumber those due to excessive accelerations by a five-to-one ratio. This two-volume report presents the results of a study of the effectiveness of airbags in reducing the severity of contact injury to the gunner when striking the gunsight. Airbag systems were installed on the gunsights in simulated Cobra and Apache cockpits, then sled tested at 7 and 25 g. The tests indicated airbags reduced head accelerations by 65 percent, head injury criteria by 77 percent, and head angular acceleration by 76 percent in the Cobra tests. In the Apache tests, the airbags reduced those same indicators by 68, 52, and 83 percent. An airbag system, the report concludes, is likely to prevent severe or fatal head and chest injuries in an Apache or Cobra crash. Volume 1 of the report describes the tests and discusses the results. Volume 2 consists of Appendixes A, B, and C of the report and contains processed signal graphs of all sled tests. Volume II is available upon request from SIC, USAARL.

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Contents

List of figures

List of tables

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Summary

A recent review of Army accident investigation records to document injuries sustained in Army helicopter crashes showed injuries due to excessive accelerations have been reduced in Apache (AH-64) and Black Hawk (UH-60) crashes compared to other helicopters. This injury reduction may be attributed to current Army design standards which feature energy-absorbing landing gear and seats, and increased high mass item retention. Significantly, contact injuries of pilots outnumbered acceleration injuries by a five-to-one ratio. Contact injuries occur when the pilot strikes a structure inside the cockpit because of inadequate restraint or because of collapse or intrusion of the structure.

The Apache optical relay tube (ORT) and the telescopic sighting unit (TSU) in the Cobra (AH-1) are used by the gunner (front-seat copilot) for target sighting, ranging, and designation. Since the TSU and ORT present potential contact hazards to the gunner, this investigation focused on Apache and Cobra crashes.

Accident investigation records at the U.S. Army Safety Center (USASC) were examined to determine the frequency of gunner injuries incurred from striking the TSU and ORT during survivable mishaps. Gunner injuries were attributed to the TSU in 20 of the 105 survivable Cobra crashes during the 1972-1980 period. Gunners in nine of these cases received minor injuries while five sustained major ones. The remaining six gunners received fatal injuries. The Apache had eight survivable mishaps since its fielding in 1985. Of these, only one gunner sustained a concussion and skull fractures as a result of his head striking the ORT. In this Apache mishap and in the 11 Cobra cases where major or fatal injuries occurred, it was theorized an airbag would have prevented serious injuries.

To explore this theory, 32 sled tests were conducted at the Naval Biodynamics Laboratory (NBDL) in New Orleans, Louisiana. Eleven of the tests simulated a 25 g impact of the Cobra/TSU, a severe but survivable crash. An additional 12 tests of 7 g simulations of the Apache/ORT were designed to simulate the early portion of the deceleration pulse produced by the collapse of Apache landing gear. The test manikin (dummy) which was used to represent the gunner was restrained by the standard 5-point belt system and inertia reel and wore the appropriate flight helmet. Components of the Cobra or Apache cockpits essential for realistic simulations were incorporated in the test hardware. The remaining 9 tests were intended to duplicate the conditions of the first 23 tests, except that an airbag was installed below the sighting system in an attempt to cushion the head and reduce the severity of its strike.

Head strikes did occur in most tests despite the proper functioning of the restraint systems and inertia reels. In all tests without airbags, dummy head accelerations indicated head strikes were sufficiently severe to cause facial fractures, but not necessarily irreversible brain damage. Airbags proved extremely effective in reducing the severity of head strikes against sighting systems regardless of inertia reel function. For example, using mean values of several indicators of injury severity, airbags reduced head accelerations by 65 percent, head injury criteria by 77 percent, and head angular acceleration peak-to-peak swings by 76 percent in the Cobra/TSU tests. In the Apache/ORT tests, the airbags reduced those same indicators by 68, 52, and 83 percent, respectively.

This U.S. Army Aeromedical Research Laboratory (USAARL) study demonstrated that airbags reduced head injury severity assessment indicators. Since this was a preliminary study, the research efforts were limited to off-the-shelf automotive airbags with minimal hardware modification. An airbag system, specifically designed for Apache or Cobra, likely would prevent severe or fatal head and chest injuries. It is recommended that U.S. Army Aviation Systems Command (AVSCOM) initiate R&D efforts to further develop the airbag concept for use in Army helicopter cockpits to supplement standard restraint systems.

Introduction

The AH-1 Cobra was first introduced into combat service by the U.S. Army in 1967 to serve as an attack and antiarmor helicopter. Since its introduction, it has undergone a number of upgrades to improve its performance and weapons capability. In 1985, the AH-64 Apache was fielded as a new generation attack helicopter offering marked improvements in performance and armaments, and an ability to operate at night and in poor weather conditions. The AH-1 and AH-64 function as attack helicopters operating in a high threat environment. Even in peacetime, the training missions for these aircraft subject their pilots to high risks of injury. Flying nap-of-the-earth (NOE) and having to "high hover" during bore sightings and firings frequently places these aircraft in the "dead man" zone of altitude versus airspeed where recovery is difficult in the event of an emergency.

A common feature of both aircraft is the presence of a gunsight in the front cockpit used for target sighting, ranging, and designation of the TOW or Hellfire missiles. In the AH-1, the gunsight is referred to as a telescopic sighting unit (TSU) and in the AH-64, it is an optical relay tube (ORT). From a crash injury perspective, there are two major differences between the TSU and the ORT. The ORT is located physically closer to the crewmember, and it has a breakaway system that allows it to yield to excessive forces generated by the striking of the crewmember's body during a crash. Because of the presence of the respective sighting systems, the copilot/gunner in both types of helicopter can sustain serious or fatal injuries if his upper body strikes the gunsight during a crash. Of particular concern is the potential for serious head injury from head strikes on the TSU or ORT.

Accident history

Injuries occurring in U.S. Army helicopter crashes have been documented by numerous studies over the past 25 years (Adams and Hicks, 1979; Bezreh, 1963; Haley, 1971; Hicks, Adams, and Shanahan, 1982; Mattox, 1968; Sand, 1978; and Shanahan and Shanahan, 1989a). From these studies, we know most potentially survivable helicopter crashes involve near vertical impacts with terrain and most injuries arise from forces generated along the vertical axis. Consequently, new design standards for crash resistant helicopters emphasize reducing crash forces along the helicopter's vertical axis. Current Army design standards require forces to remain within tolerable limits at all occupiable positions for vertical impacts of up to 12.8 m/s (42 ft/s) on a hard surface (Shanahan and Shanahan, 1989b). The generally accepted vertical acceleration tolerance limit for service age individuals is 20-25 g (1 g = 9.80665 m/s^2) for approximately 100 ms. To achieve this desired design goal requires some ingenuity since stopping distance in a vertical crash usually is small. This is due to the relative lack of crushable structure on the bottom of standard fuselages and the poor deformation predictability of most impacted surfaces. Meeting the standard requires energy-attenuating capability be provided in the landing gear, fuselage floor, aircraft seating, or any combination of the three. Both the Apache and Black Hawk helicopters incorporate energy-attenuating landing gear and stroking seats. As we will discuss below, the addition of these features modifies the crash pulse of these helicopters in comparison to other noncrashworthy helicopters.

The crash experiences of both the Apache and the Black Hawk have shown the energy-absorbing features work extremely well since impacts with vertical velocities in excess of 12.8 m/s (42 ft/s) are survivable in both helicopters. Nevertheless, a significant number of injuries still are occurring in survivable crashes of these helicopters. A recent review of injuries sustained in Army helicopter crashes demonstrated injuries due to excessive acceleration are, in fact, reduced in Apache and Black Hawk crashes compared to other helicopters (Shanahan and Shanahan, 1989a). Significantly, for all helicopters, contact injuries outnumbered acceleration injuries by a ratio of approximately five to one. Contact injuries arise from secondary collisions that occur when an individual strikes or is struck by an object. These contact injuries are due to inadequate restraint, collapsing structure, or a combination of both mechanisms. Since the TSU and ORT represent a significant potential contact hazard in spite of the use of five-point restraint systems, the Cobra and Apache represented an excellent model for exploring the efficacy of the use of airbags in preventing contact injury in helicopter crashes. The testing project which is reported here also provided an opportunity to compare a dual-sensing inertia reel with the standard MA-6 inertia reel using two different lock activation settings.

As part of this project, USASC accident records of the Cobra and Apache were reviewed to document the frequency of injuries incurred from striking the TSU or ORT. All survivable ground impact mishaps of the AH-1 from 1 January 1972 to 30 June 1990 were reviewed. During this 18.5 year period, there were 105 crashes of the Cobra classified as survivable or partially survivable and for which the vertical velocity at terrain impact was greater than zero. Of these crashes, 20 (19 percent) resulted in injury to the copilot/gunner as a result of striking the TSU. Six individuals (6 percent of all crashes) received fatal injuries, another five received major injuries, and nine received minor injuries.

It should be noted, in the six fatal crashes, the copilot/gunner (front seat) died as a result of striking the TSU (five head strikes and one chest impact) while the pilot (rear seat) sustained only relatively minor injuries. Even though the accident reports suggested two of the six individuals failed to properly tighten their upper torso harnesses, we concluded the fatalities would not have occurred in the absence of the TSU. In all accidents resulting in major or fatal injuries from striking the TSU (a total of 11), it was felt an airbag would have prevented serious injury.

When velocities at ground impact for those accidents resulting in major or fatal injury were compared to other accidents of the AH-1, there was no significant difference (student T-test, $p > .05$) in the vertical velocity between the two groups: 5.33 m/s versus 3.47 m/s (17.5 ft/s versus 11.4 ft/s). However, the mean longitudinal velocity at impact for crashes resulting in major injury from TSU strikes was more than twice that of those that did not involve TSU strikes: 20.6 m/s versus 8.72 m/s (67.7 ft/s versus 28.6 ft/s). All fatal injuries occurred at impact velocities over 10.3 m/s (33.8 ft/s) except for one case of 2.1 m/s (6.8 ft/s) where the individual reportedly failed to tighten his upper torso restraint. Furthermore, only one chest or head injury occurred at a longitudinal impact velocity of less than 5.2 m/s (16.9 ft/s), except for the one case described above. These data suggest TSU strike injuries, unlike most helicopter crash injuries, are relatively independent of vertical velocity at impact and highly dependent on longitudinal velocity.

Mishap records of the AH-64 covering the period since its fielding in 1985 to 30 June 1990 also were reviewed. There were eight survivable ground impact mishaps of the Apache. Only one resulted in injury to the copilot/gunner as a result of striking the ORT. In this case, the crewmember received a concussion and facial fractures. The estimated vertical velocity was 9.44 m/s (31 ft/s) and the longitudinal velocity was 2.56 m/s (8.4 ft/s). Also, there was a nonsurvivable crash of an Apache where the copilot/gunner sustained a forehead laceration when he struck the ORT. The vertical velocity at impact was estimated to be 15.5 m/s (51 ft/s) and the longitudinal velocity was less than 1.1 m/s (3.5 ft/s).

Although there is very little experience with crashes of the Apache, it seems clear the ORT is a significant hazard to the front seat occupant in spite of its breakaway design. Furthermore, the combination of energy-attenuating landing gear and a stroking seat in this helicopter, as well as the closer proximity of the ORT compared to the TSU, makes contact with the ORT less dependent on longitudinal velocity than in the case of the AH-1. If this hypothesis is correct, we can anticipate a higher rate of gunsight strikes in the Apache than we have experienced in the Cobra.

An additional factor to consider is in the AH-64: The impact energy-attenuating design of the airframe modifies the impact forces so the impact duration is longer. The longer duration results in lower torso accelerations that may not generate the 2 g to 3 g upper torso acceleration required to lock shoulder harness inertia reels sufficiently early to prevent a head strike on the ORT. Therefore, the standard 2-3 g setting of the shoulder harness inertia reel may not provide an appropriate degree of protection for the front seat occupants in the AH-64.

One approach to remedy the head strike problem in the Apache and Cobra would be to change the locking parameters of the shoulder harness inertia reel so the reel locks earlier in the impact sequence, thus reducing the forward movement of the torso and head. Another approach would be the addition of an energy-attenuating device between the head and the sighting system. One such device is the rapidly inflating airbag currently installed in several models of automobiles. The passive airbag can be placed in the cockpit and tailored so as not to interfere with the normal operation of the controls, but can be deployed rapidly by means of a sensor and diagnostic system sensing the impact accelerations of the aircraft striking the ground.

Objectives

The objectives of this two-phase investigation were:

a. To analyze data from accident investigations of AH-1 and AH-64 mishaps in which injuries were produced by the gunner (copilot) striking the TSU or ORT.

b. To document the movement of the helmeted head with respect to the sighting systems during simulated crashes in the AH-1 and AH-64 front seats.

c. To examine the capability of the inertia reel and shoulder harness restraint system to prevent head strikes on the gunsight system during simulated crashes.

d. To explore the concept of using rapidly inflating air cushions and to assess the potential usefulness of this technology in reducing the severity of head strikes on the gunsight system during actual crashes.

Test methods

The testing to accomplish the objectives of the project were performed in two phases. The first took place in October 1988 and the second in October-November 1989. The tests were conducted at NBDL using a sled driven by a horizontal linear accelerator to generate the simulated impact forces.

To perform multiple simulated impacts and observe the interaction of the test manikin in the front seat environment of the Cobra and Apache, test devices were fabricated using a combination of the actual aircraft hardware and an adjustable attitude support structure. The aircraft hardware used for the Cobra tests included the distal section of the TSU, the Cobra restraint system with the inertia reel, and the Cobra armored seat and bottom seat cushion. The back seat cushion also was included in the simulated structure. An overall view of the setup for tests with the Cobra and TSU is shown in Figure 1. The hardware used in the Apache tests included the full Simula™ Apache energy-absorbing crew seat* and seat cushions*, the AH-64 restraint system with the inertia reel, and the distal direct viewing section of the ORT. The bottom section of the ORT that contains the ORT control box and a CRT were simulated using a specially fabricated box with lead weights to duplicate the actual structural weight. An overall view of the Apache test setup is shown in Figure 2 with the ORT installed in the front portion of the test fixture.

The mount of the ORT was designed to collapse when the impact force exceeded 400 pounds. A closeup of the mounted ORT is shown in Figure 3. To retain the frangibility of the ORT in the test fixture while providing a reusable test apparatus, the original mounting bolts that held the upper portion of the relay tube to its base were substituted with nylon screws selected to fail in shear and to be easily replaced. The 400-lb collapse threshold was verified by testing the new assembly in static compression as shown in Figure 4.

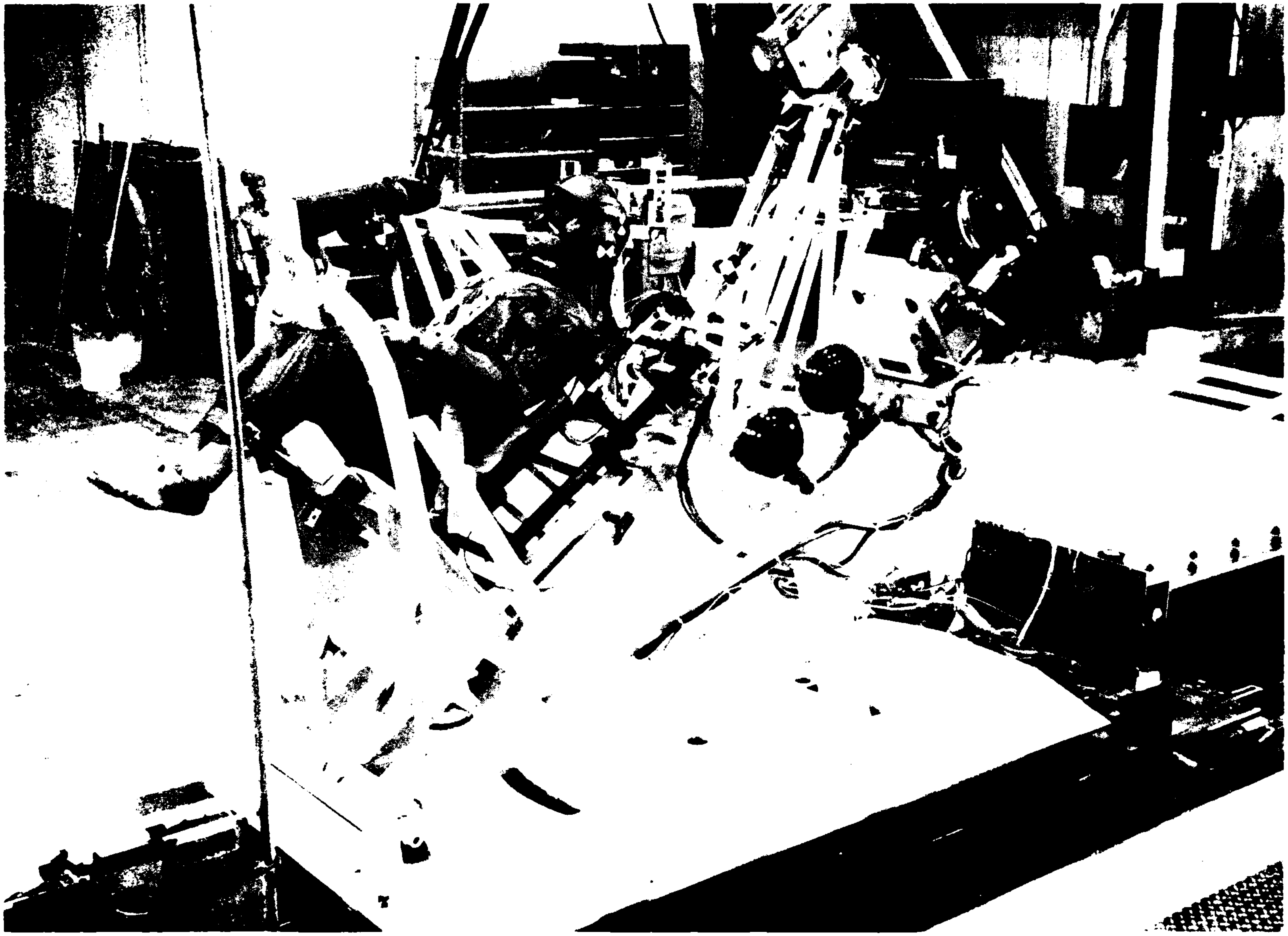

Figure 1. View of the Cobra TSU 35-degree test setup.

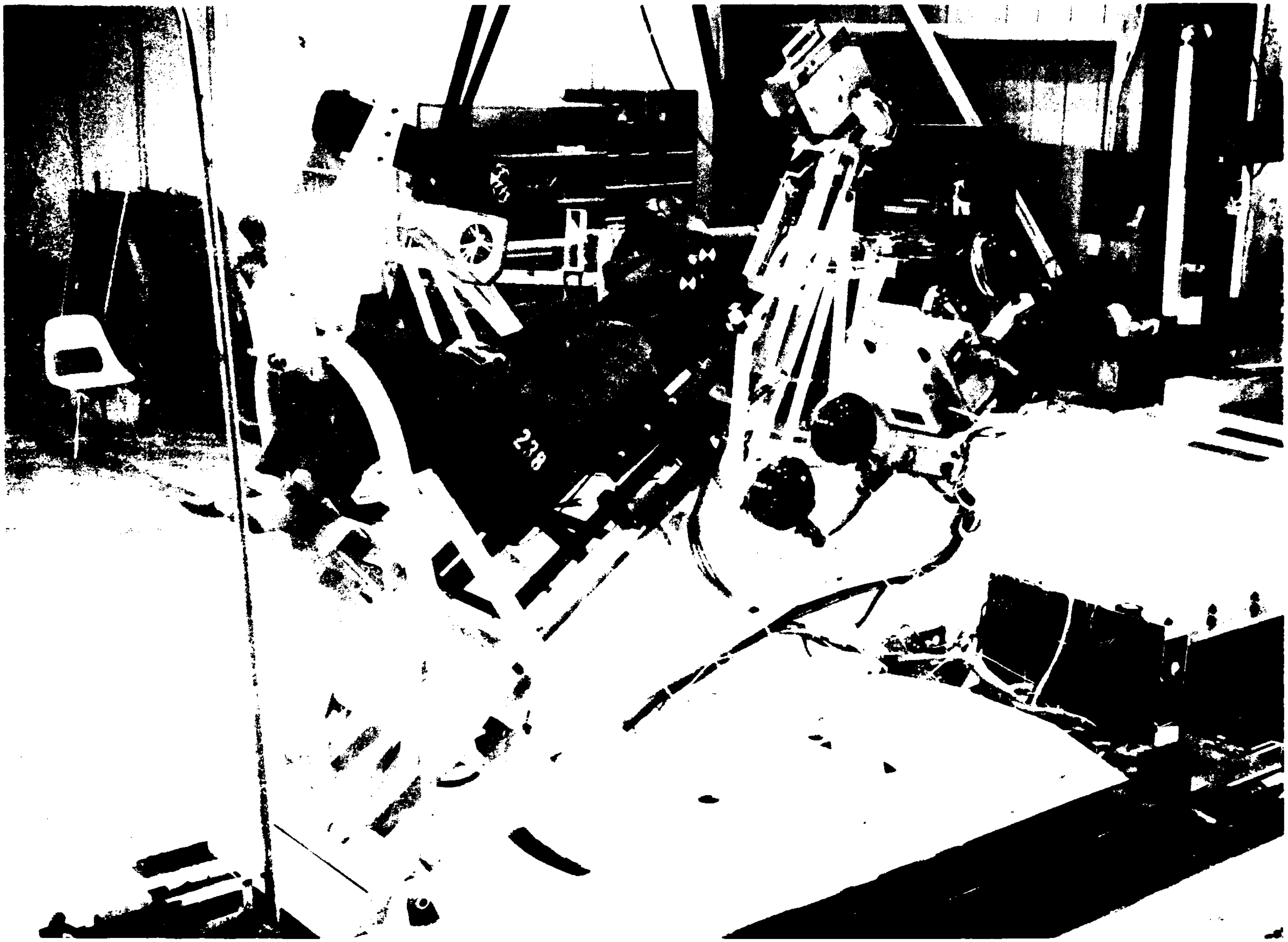

Figure 2. View of the Apache ORT 35-degree test setup.

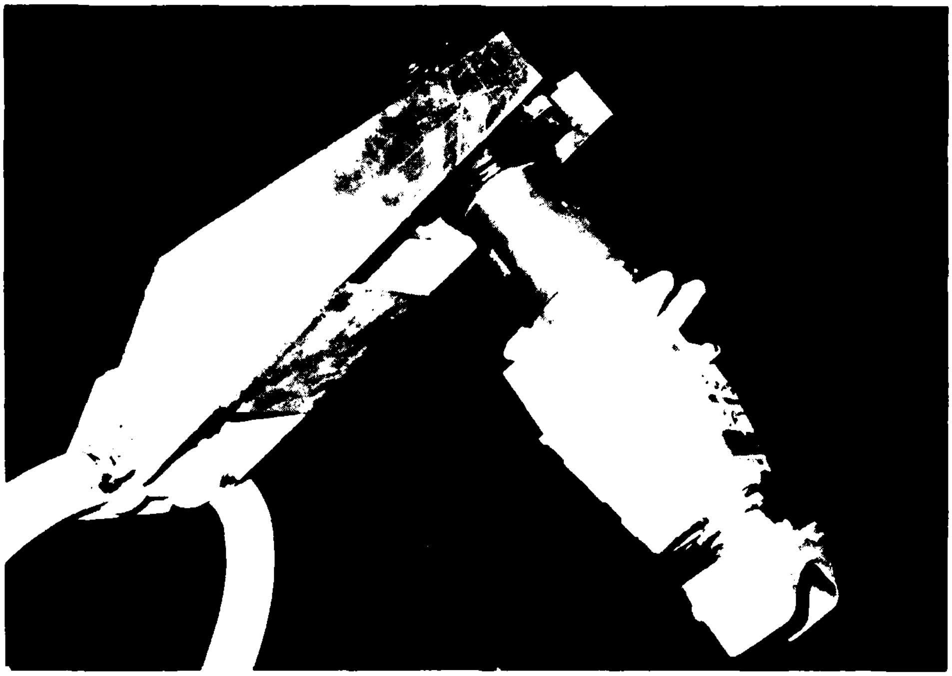

Figure 3. Close-up view of the Apache ORT mounted on the sled test frame and showing its base and the breakaway nylon mounting screws.

Figure 4. View of the hydraulic compression test device used to test the strength of mounting screws.

The test subject was a 50th percentile Hybrid III manikin* (serial number D-007) with a nominal weight of 80 kg (176 lb) and a stature of 178 cm (70 in). This manikin was designed in the early 1970s by General Motors Research Laboratories to improve the biofidelity of impact response of the U.S. Department of Transportation (DOT) standard anthropomorphic Hybrid II test device, referred to as Part 572 ATD. The manikin was dressed in an Army flight suit and boots, and its head fitted with either the SPH-4 aviator helmet for the Cobra tests or the integrated helmet and display sighting system (IHADSS) helmet for the Apache tests. Although the manikin had a standard Hybrid III neck, the head itself was modified from a Part 572 head to allow the use of a frangible face, an element designed and fabricated at NBDL. Figure 5 shows the frangible face.

The NBDL frangible face consisted of a core of foam and aluminum mesh covered by a 15-mil (0.015-in) thick aluminum witness plate, all covered by a silicon rubber humanoid skin. This face was mounted on the modified Part 572 ATD head which had its face removed and a flat mounting plate welded in its place. When the face received an impact during a test, the underlying foam and aluminum structures deformed permanently. Posttest examination of the face indicated whether or not the face (i.e., head) struck the ORT or TSU. Additional indication of any head contact with the viewing structure was obtained by rubbing blue chalk over potential strike locations of the ORT and TSU. Upon the completion of a test, any blue chalk marks found on the face indicated a head strike. This is a common method used in manikin impact tests to indicate the occurrence of an impact but not its severity. Initially, we planned to calibrate the frangible face by correlating depths of indentations with known force levels. This would have allowed head impact forces to be estimated. Since this calibration procedure was not performed prior to testing, no quantitative data was obtained from the frangible face.

The primary objective of the first phase of this project was to examine the capability of the MA-8 rate-sensitive inertia reel (per MIL-R-8236E) and restraint system to prevent head strikes on the sighting system during simulated crashes when the inertia reel was placed in the automatic mode. This was done in two ways. First, tests were conducted at two lock activation settings: 1.2-1.8 g (nominally a 1.5 g setting), and 1.5-3.5 g (nominally a 2.25 g setting). These levels refer to the linear acceleration of the strap as it unwinds from the inertia reel. An alternative approach to changing the locking parameters was to use a new type MIL-4-8236, MA-10 inertia reel which has a dual acceleration sensing system. One part of this dual-mode system operates much like the standard MIL-4-8236 MA-6 and MA-8 reels. It was set to lock at 1.2-1.8 g linear acceleration of the

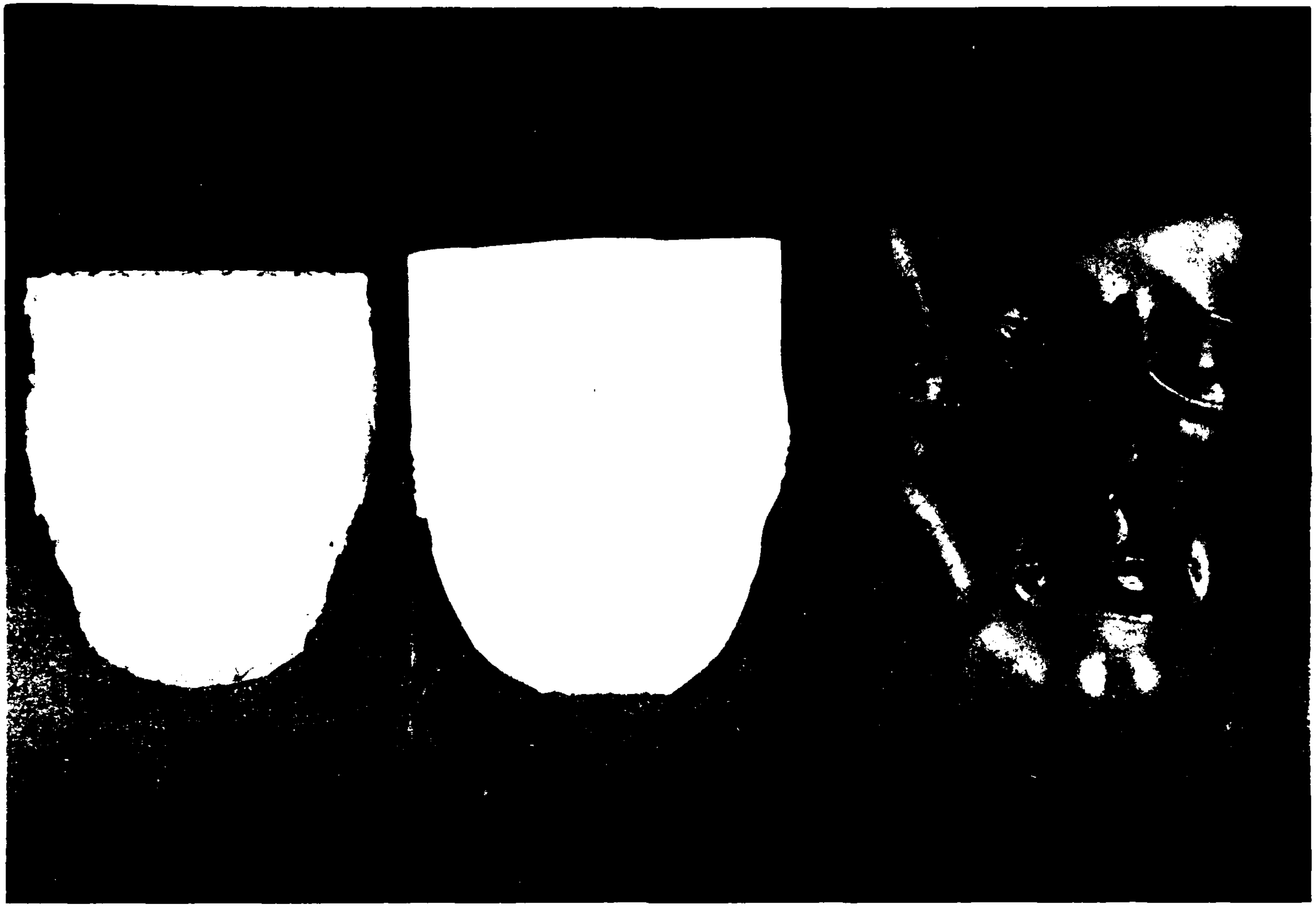

Figure 5. Components of the manikin frangible face developed by NBDL and used to detect head strikes.

unwinding strap. The second part of the MA-10, which senses the impact accelerations of the seat pan, was set to activate the lock at 4-5 g in the x- or z-axis.

A cockpit support structure was constructed to permit quick reconfiguration of test hardware and modifications of the impact parameters. The structure included a hinge at one end to allow for different pitch orientations. Although the test device was capable of introducing yaw in 5-degree increments, the objectives of this phase of the test did not necessitate the introduction of yaw as a factor. On horizontal sleds such as the one used at NBDL for this project, vertical impacts typically are simulated by placing the seated subject with the seat back nearly parallel to the horizontal tracks. Since the manikin longitudinal spinal axis is laid along the seat back, the direction of the impact vector relative to the spine is equal to the angle between the seat back and the sled tracks.

Two onboard high-speed film cameras, each running at 500 frames/second, were used to record the motion of the manikin head, the restraint system, head strikes, and airbag deployment. One camera was mounted on the left side of the sled while the second was mounted above and behind the seat in order to view the manikin head and shoulder and the unwinding of the shoulder strap out of the inertia reel. In the second phase of testing, these cameras were supplemented by a 200 frame-per-second video camera for quick look, and two 1000 frame-per-second film cameras, all placed offboard.

During inertia reel testing (phase 1), a head-mounted tri-axial accelerometer was used to record linear accelerations of the head. In the second phase of testing, two head-mounted angular accelerometers were added to record head roll about its forward axis and pitch about its lateral axis. In all tests, sled acceleration was recorded.

Whenever possible, the unwinding of the shoulder strap out of the inertia reel was monitored using a string potentiometer* (Celesco™ Model PT-101-75B). The potentiometer was installed near the inertia reel housing and its string end attached to a convenient point on the moving strap.

In the second phase of this project, the standard restraint system was supplemented with an air cushion system mounted at a convenient location on the ORT or TSU. As previously mentioned, the purpose of this phase was to explore the concept of using air cushions to improve the effectiveness of the current restraint system in reducing the severity of head strikes on the sighting system during simulated crashes. Details of bag design, placement, and activation parameters were not addressed since they are beyond the scope of this concept test.

An off-the-shelf and locally available automotive airbag system was selected for the tests. The system was a driver's side airbag designed by Honda Motor Company* as a supplemental restraint system to fit in the steering wheel of its Acura Legend model. Because the intent of the tests was to demonstrate the concept and not to develop a customized version of the air cushion, only minimal modifications were added to the external mounting hardware to allow the airbag to function as intended. For example, the automotive airbag used in the tests was designed to take advantage of the steering wheel rim to provide a back support during its inflation and potential driver's head and chest movements into it. Since neither the TSU nor ORT had such a rim, it was necessary to fabricate and install a reaction plate that provided the back support needed for proper functioning of the airbag. A photograph of the reaction plate which was used in the Cobra TSU tests is given in Figure 6. The size of the plate was reduced substantially in later tests as experience with the airbag deployment pattern was gained. The mounting and support structure of the airbag used in the Apache ORT tests are shown in Figure 7.

During testing, it was necessary to make several "dry runs" where the instrumentation, test fixtures, and sequence of events were carefully checked. Since these runs required firing of the sled, a reference number was assigned to each firing. Except when necessary to fine tune instrumentation, no signals were monitored during these dry runs.

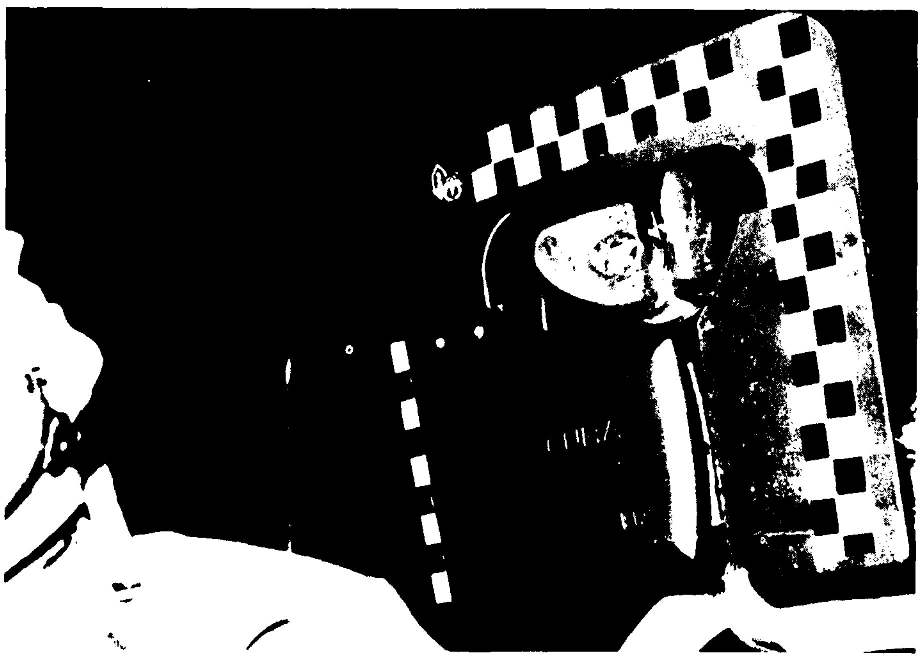

Figure 6. Structure used with the Cobra TSU airbag tests to provide back support to the inflated airbag.

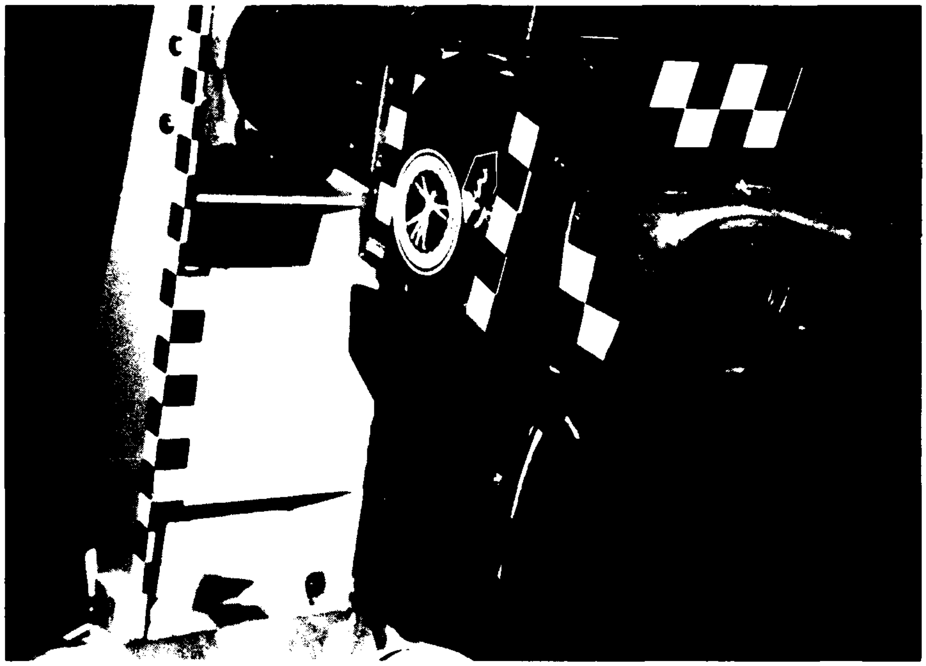

Figure 7. Structure used with the Apache ORT airbag tests to provide back support to the inflated airbag.

Data processing

Two primary categories of data were generated during this project: transducer signals and high-speed films. Less formal but equally informative were the observations recorded on the spot during each test by the investigators and still photographs which were taken at various stages of each test.

Quantitative film analysis can yield motion measurements which cannot be obtained by other recording means. However, extensive field calibration procedures must be implemented if accurate measurements are to be made. This was not done for this project, so no quantitative motion analysis was performed. However, high-speed films provided excellent visual records of the impacts and were reviewed to identify hardware failures and to understand the interaction between the manikin and the tested restraint system.

Transducer data were the primary basis for assessing the severity of head strikes with the sighting systems and, hence, the success or failure of the tested restraint system. Transducer signals were digitized by the NBDL data acquisition system later were analyzed by NBDL and results of the analysis forwarded to the U.S. Army Aeromedical Research Laboratory (USAARL) for use in this report. In addition, NBDL staff extracted all transducer signals from their signal acquisition system and provided USAARL with the unprocessed signals for further processing and analysis (Muzzy, 1990).

All signal processing conformed to Society of Automotive Engineers, SAE J211 (1988) guideline for instrumenting and filtering impact test accelerations. Thus, all signals were digitized at the rate of 8000 samples per second, and all signals were digitally filtered according to the same SAE J211 channel class filters. Head linear acceleration signals were filtered using a digital filter simulating the SAE channel class 1000 which essentially is a Butterworth filter with its 3-dB corner at 1650 Hz and a roll-off of 24 dB/decade. Sled pulse was filtered with channel class 60 (100-Hz and 24 dB/dec.) Head angular accelerations (pitch and roll) also were filtered with the channel class 60 filters. Potentiometer signals, which measured the extension of the restraint shoulder belt, were filtered with a channel class 180 filter (300 Hz at 24 dB/dec.)

The sled acceleration pulse was integrated to produce a velocity time-history, from which the velocity change could be extracted. The onset of the sled acceleration pulse, defined as the slope (derivative with respect to time) of pulse during its rise, was used as an additional indicator of the severity of the crash. This onset rate as well as other potentially significant time derivatives (rates) were obtained from the jerk, a signal derived from acceleration by numerical differentiation.

Head accelerations included the forward (X), lateral (Y), and longitudinal (Z) components. Resultant head acceleration signals were computed as the point-by-point square root of the sum of the squared components. The head injury criterion (HIC) was derived from the resultant head acceleration using a standard procedure (Department of Transportation, FMVSS 208). Angular accelerations of the head (pitch and roll) were integrated once to produce angular velocities and a second time to produce pitch and roll angular displacements of the head.

Recorded signals were of sufficient duration to capture the rebound impact some 300-400 ms after T-zero, the onset of the sled deceleration pulse. However, the rebound impact was irrelevant to the objective of the simulations, which was to assess the severity of the first impact with the optical system. Therefore, plots of most linear and angular head accelerations were restricted to the first 200 ms where the impact of interest usually occurred. Peak values were picked automatically by the computer processing program. However, the program could not consistently read the correct swing between a high and an adjacent low in the head pitch and roll acceleration and velocity signals. Therefore, this was done manually for the swing nearest the time of head impact.

Belt extension, obtained with a potentiometer, was differentiated with respect to time to produce the rate (m/s) at which the belt was unwinding from the inertia reel. A second differentiation was done to produce the acceleration (g) at which the belt was moving. Belt acceleration triggers the locking mechanism in both the MA-6/8 and the MA-10. The differentiation procedure was used to calculate the belt linear acceleration in lieu of an actual accelerometer measurement which was difficult to accomplish.

It should be noted that signals derived by numerical differentiation are extremely noisy and must be heavily smoothed before a recognizable signal is produced. The process is useful insofar as indicating general trends but not exact measurements. Therefore, numbers extracted from these signals, such as the peak onset rate of the strap and strap peak acceleration, should be interpreted with caution.

Test conditions

In general, vertical impacts were simulated on horizontal sleds by aligning the seat back with the horizontal sled tracks. Because of gravity, the downward weight of the manikin combined with the acceleration forces (opposite to the direction of sled acceleration) to produce a thrust vector which slightly inclined relative to the sled horizonal axis. Therefore, to generate impact forces along the manikin spinal (longitudinal) axis, the seat was rotated by an offset angle determined by the average sled acceleration. A seat back angle of 5 degrees with the horizontal was considered adequate compensation for the effect of gravity in our tests. Three directions, defined by seat back angles of 5, 20, and 35 degrees with respect to the tracks, were designed to generate impact forces directed 0, 15, and 30 degrees, respectively, from the spinal axis.

Test conditions and parameters are summarized in Tables 1, 2, and 3. Tests that did not involve the airbag are listed in Table 1 for the AH-1 (Cobra) and in Table 2 for the AH-64 (Apache.) All other tests involving the airbag are listed in Table 3. Tests with repeated or similar test conditions have been grouped together even though they may have been conducted in a different order, as reflected by their reference numbers.

Table 1.

Summary of conditions and results of the inertial reel tests with the AH-1 (Cobra) telescopic sighting unit (TSU).

Test reference number	Sled pulse		Pitch angle	Head resultant acceleration		Angular acceleration swing at impact		Angular velocity swing at impact	
	Accel-eration (G)	Veloc-ity (m/s)	(deg)	Peak (G)	Head injury criterion	Roll (rad/s^2)	Pitch (rad/s^2)	Roll (rad/s)	Pitch (rad/s)
LX6196	19.6	11.1	5	42.4	157	305	3010	2.1	30.5
LX6197	19.0	11.0	5	43.3	119	455	3680	3.0	35.2
LX6198	19.6	11.0	5	40.3	102	505	3935	3.1	32.8
LX6199	23.5	12.0	5	60.6	249	995	5600	4.0	40.8
LX6200	23.4	12.0	5	65.7	250	805	5250	3.6	43.2
LX6201	23.4	12.0	5	49.8	245	700	5505	5.1	40.0
LX6203	25.0	12.3	35	138.3	**	3000	17000	13.9	79.5
LX6204	25.0	12.3	35	128.8	1244	2720	11500	8.6	61.0
LX6274	25.0	11.1	35	86.9	498	1295	10320	4.5	73.6
LX6275	25.0	11.1	35	141.8	594	4160	18560	8.4	86.5
LX6276	25.1	11.2	35	195.0	615	1425	8700	6.2	54.4

** Data unavailable or clearly inaccurate

Table 2.

Summary of conditions and results of the inertial reel tests with the AH-64 (Apache) optical relay tube (ORT).

Test reference number	Sled pulse		Pitch angle	Head resultant acceleration		Angular acceleration swing at impact		Angular velocity swing at impact	
	Accel-eration (G)	Veloc-ity (m/s)	(deg)	Peak (G)	Head injury criterion	Roll (rad/s^2)	Pitch (rad/s^2)	Roll (rad/s)	Pitch (rad/s)
LX6208	7.7	10.7	35	93.5	159	1550	14000	4.8	50.4
LX6209	6.7	10.7	35	31.8	42	535	6040	3.0	48.0
LX6210	6.8	10.7	35	27.4	35	580	5840	2.6	41.6
LX6211	6.8	10.7	35	39.9	51	695	7420	2.5	48.0
LX6212	6.8	10.8	35	26.2	27	505	7020	1.3	30.5
LX6213	6.8	10.7	35	35.4	55	695	7440	2.9	51.2
LX6277	8.9	10.8	35	52.6	82	1040	6800	2.3	40.8
LX6283	25.9	11.4	35	251.4	1357	3970	12400	15.2	54.4
LX6214	6.8	10.8	20	80.5	126	855	16000	2.5	46.5
LX6215	6.8	10.7	20	53.0	68	800	8880	2.6	49.6
LX6216	6.8	10.7	5	70.5	99	1070	11600	3.0	47.2
LX6217	6.7	10.8	5	15.8	**	**	**	**	**

** Data unavailable or clearly inaccurate

Table 3.

Summary of conditions and results of G-triggered airbag sled tests simulating 35-degree impact.

Test reference number	Sled pulse		Tested system	Head resultant acceleration		Angular acceleration swing at impact		Angular velocity swing at impact	
	Accel-eration (G)	Veloc-ity (m/s)		Peak (G)	Head injury criterion	Roll (rad/s^2)	Pitch (rad/s^2)	Roll (rad/s)	Pitch (rad/s)
LX6270	20.3	10.8	Cobra TSU	43.2*	207*	830	2815	4.9	29.4
LX6271	23.2	11.5	Cobra TSU	43.6*	190*	575	3840	6.5	23.2
LX6272	25.0	11.2	Cobra TSU	42.7*	133*	1840	3020	11.2	15.6
LX6273	24.7	11.1	Cobra TSU	52.9*	168*	1470	**	6.8	**
LX6278	6.7	9.0	Apache ORT	13.0	26	465	1500	2.9	8.0
LX6279	7.1	9.3	Apache ORT	14.6	35	470	1100	1.7	4.6
LX6280	27.8	11.7	Apache ORT	210.4	1566	2350	11440	15.4	40.8
LX6281	25.5	11.3	Apache ORT	67.7	398	1280	3650	13.4	20.3
LX6282	25.6	11.7	Apache ORT	95.7	569	1840	6600	14.6	34.8

* Actual peak slightly higher than indicated.
** Data unavailable or clearly inaccurate.

Two crash severities were simulated by programming the sled to produce the appropriate acceleration pulses. The two pulses selected for this project differed primarily in the magnitudes of the acceleration (25 g and 7 g nominal peaks) while essentially maintaining the same velocity of 11-12 m/s (36-39 ft/s). The 25-g pulse simulated a severe but survivable crash. The 7-g pulse was intended to simulate the first 70-80 ms portion of a collapsing "load-limiting" gear where the acceleration dwells at the 7-g level. In a typical crash involving the landing gear, the long-duration, low-level pulse may be followed by a 50-100 g peak pulse which is generated as the landing gear bottoms out. Since this complex acceleration pulse was not achievable with the NBDL sled, it was deemed more important to simulate the early portion of the impact with the available sled.

Two different settings of the MA-6/8 were tested: 1-2 g and 2-3 g settings. This was done to test whether the lower g setting would activate the inertia reel lock sooner resulting in a noticeable reduction of head strikes. The MA-10 had a dual sensing system which locked the reel at a 1-2 g setting or when the impact produced a seat acceleration level of 4-5 g in the X- or Z-axis.

Several preinflated airbag tests were conducted to explore the kinematics of interaction between the manikin and the airbag. No presentable data were produced from these "dry runs" so no results are reported here. The airbags in the remaining tests (five Cobra TSU and six Apache ORT) were allowed to inflate upon impact, triggered by a signal from an automotive-type crash sensor. This device, which was designed for use in automobiles, detects the onset (initial rise portion) of a crash pulse and electronically triggers the locking mechanism of the car seat belts or the squib used to inflate the airbag. In the sled airbag tests, the crash sensor was attached to the sled so as to generate the triggering signal when the sled acceleration pulse reached 4-5 g. All 10 airbag tests (Table 3) simulated 35-degree impact direction and most used the MA-10 dual mode inertia reels.

The test conditions described above were not designed to fully simulate all potential crash scenarios nor were they intended for statistical analyses. However, they do form a representative sample and serve to illustrate some advantages and shortcomings of current and future restraint systems.

Test results

Detailed results of the data analysis are presented in Appendixes A, B, and C, found in Volume II, in the form of processed transducer signals. Volume II may be obtained upon request from the Scientific Information Center (SIC) at USAARL. Several tests were run in addition to the 32 included in this report. Most of these were developmental runs and did not generate reportable data. Only the fully instrumented tests are reported. Selected response parameters were extracted from these signals and summarized in Tables 1, 2, and 3. The first two tables summarize the results from tests which did not involve the use of an airbag. The third table summarizes data from all tests with airbags. The tables list peak resultant linear acceleration (g) of the head and the computed HIC. The validity of the HIC as an assessment method will be discussed in the next section. The head angular motion is reported in the tables as the "swing" between the low and high nearest the time of head strike. Swings of angular accelerations (rad/s^2) and velocities (rad/s) are tabulated for both roll and pitch. Head pitch is defined as a rotation of the head about its lateral (Y) axis. Head roll is defined as a rotation of the head about its forward (X) axis. No yaw is reported since this rotation, defined as the twist of the head about its longitudinal (Z) axis, is minimal due to the design of the neck in the Hybrid III manikin.

The amount of extension (cm) of the restraint belt out of the inertia reel are listed but only when it was judged to be valid. Some of the signal processing results produced by the automated software did not make sense, particularly when compared to film data, and were discarded as erroneous. In many tests, it was possible to estimate the belt extension from film analysis by relying on the checkered pattern attached to the belt. In fact, this was the only method available for measuring the belt extension when the signal from the string potentiometer was clearly in error (because of a breakdown in the instrumentation). These estimates have been incorporated in the tables of results.

Also reported in tabular format are qualitative evaluations of the high-speed films of the tests and examinations of post-test photographs. All test films were reviewed to detect and report unusual events which could help explain certain signals or the final outcome of some tests. Film reviews focused on two areas of concern: The extension of the restraint belt out of the inertia reel, and the head strikes with the TSU or ORT. The type of inertia reel, its lock setting and action, the amount of belt extension, as well as observations of head strikes are listed in Tables 4, 5, and 6.

Table 4.

Restraint system action and manikin interaction with the TSU in the Cobra tests.

Test number	Inertia reel		Amount of belt extension (cm)	Observations †
	Type	Lock setting (G)		
LX6196	MA-6/8	2-3	1.5*	No head contact.
LX6197	MA-6/8	1-2	3.0	No head contact.
LX6198	MA-10	1-2/4-5	6.5	No head contact.
LX6199	MA-10	1-2/4-5	2.0*	Minor helmet contact.
LX6200	MA-6/8	1-2	8.0	Minor head and helmet contact.
LX6201	MA-6/8	2-3	10.8	Minor face contact.
LX6202	**	**	**	Chin and cheek contact.
LX6203	MA-10	1-2/4-5	17.5	Nose and right cheek strike.
LX6204	MA-6/8	1-2	**	Full face impact.
LX6274	MA-6/8	Prelocked	3.5	Head and full face impact.
LX6275	MA-6/8	Prelocked	2.0	Head and right cheek strike.
LX6276	MA-10	Prelocked	11.0	Head and full face impact.

* Estimated from film analysis
** Data unavailable or clearly inaccurate
† Based on review of high speed films and posttest photographs.

Table 5.

Restraint system action and manikin interaction with the ORT in the Apache tests.

Test number	Inertia reel		Amount of belt extension	Observations †
	Type	Lock setting (G)	(cm)	
LX6208	MA-10	1-2/4-5	5.4*	Full face and forehead hit.
LX6209	MA-6/8	2-3	5.7*	Full face and chin impact.
LX6210	MA-6/8	1-2	7.0*	Full face and chin impact.
LX6211	MA-10	1-2/4-5	5.7*	Chin and right face impct.
LX6212	MA-6/8	2-3	12.0	Lower face and chin impact.
LX6213	MA-6/8	1-2	5.7*	Full face strike.
LX6277	MA-10	prelocked	4.9*	Full face impact.
LX6283	MA-10	1-2/4-5	21.8	Head impact with ORT.
LX6214	MA-10	1-2/4-5	4.5	Left forehead and mouth contacts.
LX6215	MA-6/8	2-3	4.5	Mouth and forehead contact.
LX6216	MA-6/8	1-2	3.2*	Forehead and face impact.
LX6217	MA-10	1-2/4-5	**	Upper nose and forehead impact.

* Estimated from film analysis
** Data unavailable or clearly inaccurate
† Based on review of high speed films and posttest photographs.

Table 6.

Restraint system action and manikin interaction with the airbag and with the ORT and TSU in the airbag tests.

Test number	Inertia reel		Amount of belt extension (cm)	Observations †
	Type	Serial Number		
LX6270	MA-6/8	**	5.9	No head contact with TSU.
LX6271	MA-10	134	4.6	No head contact with TSU.
LX6272	MA-10	135	**	No head contact with TSU.
LX6273	MA-10	137	**	No head contact with TSU.
LX6278	MA-10	139	6.0	Head/chest imapct with airbag.
LX6279	MA-10	140	5.4	Head/chest impacted airbag.
LX6280	MA-10	141	15.8	Head struck the ORT.
LX6281	MA-10	141	10.8	Head impact with airbag but no ORT hit.
LX6282	MA-10	142	12.9	Head impact with airbag. No ORT impact.

** Data unavailable or clearly inaccurate
† Based on review of high speed films and posttest photographs.

Head strikes with the TSU or ORT also were easily detected from the head acceleration signals and by posttest examination of the frangible face. Figures 8 and 9 are typical of the deformations which were observed. Evidence of head strikes in some ORT tests also was obtained from the shearing of the nylon screws and the collapse of the ORT into its base, as shown in Figure 10.

Discussion of tests and results

The preliminary nature of this study limited the number and type of tests that were conducted. It also restricted the exploration of the airbag concept to the use of off-the-shelf hardware with minimal allowance for hardware redesign or modification. Despite these limitations, the study succeeded in demonstrating a problem exists and a supplemental airbag may be a viable solution.

Figure 8. Deformations to the manikin frangible face produced in test LX6202. These deformations are typical of those observed in most head strikes with the ORT and TSU.

Figure 9. Deformation to the manikin frangible face produced in test LX6212.

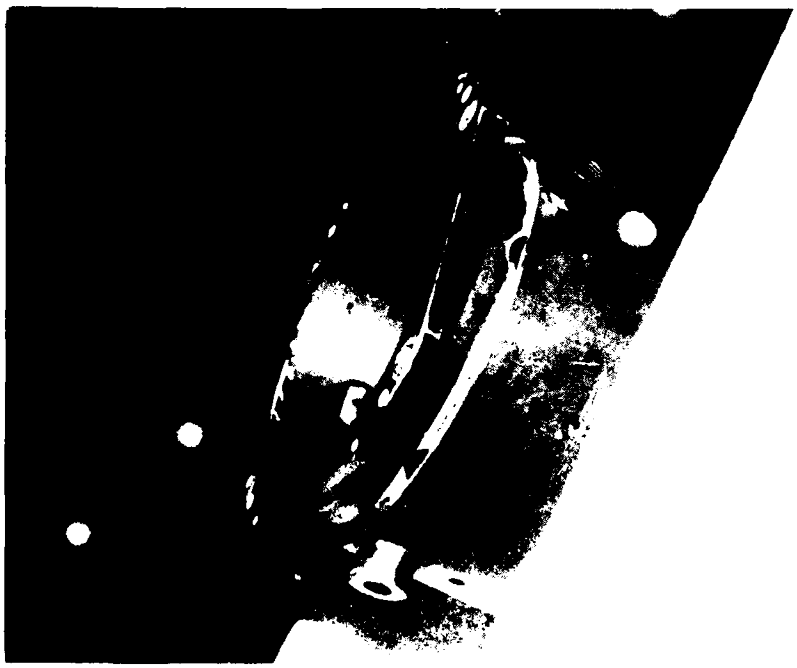

Figure 10. Evidence of severe head strikes with the ORT was obtained from stroking of the tube and shearing of the nylon mounting screws.

Epidemiological data as well as the impact tests performed under this project indicate the TSU and the ORT pose a substantial hazard to copilot/gunners in the event of a crash. The most common serious injury is facial injury, frequently associated with severe brain trauma and death. In this study, HIC was calculated from head linear accelerations to provide an objective predictor of potential irreversible brain injury. Caution should be exercised in interpreting HIC values since strict conditions must be met before any valid conclusions about head injury outcome can be derived. For example, the HIC is invalid if there were no head strikes with the ORT or TSU. Even in case of a head contact, the HIC is invalid if the duration of contact exceeds 15 ms. Usually, the duration of contact is much longer than the interval over which the HIC was determined. Finally, the HIC should not be used as a pass-fail criterion; instead, it should be used to assign probability of irreversible brain injury occurring. Thus, assuming all conditions for using the HIC have been satisfied, HIC values of 500, 1000, and 1500 may be converted respectively to 5, 15, and 50 percent approximate probabilities of brain injury (Mertz, 1984).

Furthermore, it must be stressed that HIC is a predictor of closed head injury resulting from impacts to the calvarium. Most fatal TSU injuries were open brain injuries arising from impacts to the face. The significance of this finding is that facial bones are considerably weaker than the more dense calvarial bones and yield under relatively low force. In a facial impact with the TSU/ORT, brain injury results from direct trauma from collapsing facial bones and not from the brain's inertial response to an applied force. Therefore, HIC probably is not an accurate predictor of serious injury under these conditions and can only be used as a relative measure comparing the severity of different tests.

Results of the TSU tests (Table 1 and Appendix A, Volume II) show for the six nearly vertical (5-degree) simulated crashes, head strikes were associated with lower head accelerations and HIC values than those produced by the five more pitched (35-degree) tests. That is, the severity of head strikes was lower for vertical impacts than for those with large horizontal components, as the test results indicate. This may be attributed to the difference in head trajectories relative to the impact vector produced in the two groups.

The difference between the severities would be explained as follows: At the onset of a nearly vertical impact, the head and body of the pilot travels along a vertical path that does not pass through the sighting unit. As the pitch angle of impact increases, a greater horizontal component is added to the impact vector, so the initial path of travel of the pilot's body and head passes near or through the sighting system. The head trajectory is complicated further by the unavoidable slack of the shoulder belt which is produced automatically by the slumping of the upper torso. As a result, the pilot's head would likely strike the sighting system, even when the impact primarily is vertical. This explanation is supported by field data which shows TSU impact is strongly dependent on longitudinal velocity at impact and only weakly dependent on vertical velocity.

In general, these tests were inconclusive regarding the relative effectiveness of the different inertia reels and lock settings. Using amount of belt extension and head pitch angular accelerations as indicators of inertia reel performance, the results were quite inconsistent. In the six nearly vertical Cobra TSU impacts, belt extensions varied from 1.5 to 10.8 cm (0.6 to 4.3 in). Although all reels locked, three runs had belt extensions that exceeded 6 cm (2.4 in), one run for each inertia reel condition. Ideally, belt extension should be limited to the extent possible and, preferably, to less than 5 cm (2 in) in order to prevent flail injury. The reason for such a wide range of extensions for essentially identical test conditions is not known.

The same degree of variability of belt extension was obtained in the severe TSU runs even when prelocked reels were used. Test LX6203 used a MA-10 dual sensing reel and the belt extension obtained from a string potentiometer signal was 17.5 cm (7 in). The validity of this value could not be confirmed from test film or onsite observations. The same uncertainty of belt extension applies to test LX6204, so it cannot be directly ascertained whether or not the two inertia reels locked upon impact. However, peak linear head accelerations (138.3 and 128.8 g), head pitch acceleration swings (17,000 and 11,500 rad/s^2), and pitch velocity swings (79.5 and 61.0 rad/s), as well as the damage to the frangible face, are strong indicators that the two inertia reels did not properly lock allowing the head to strike with such severity that it would have caused serious head injuries in a real crash.

Three TSU tests, LX6274, LX6275 and LX6276, were conducted later in the project under test conditions similar to the two severe TSU tests discussed above. This time, extensions of the belt were monitored with a string potentiometer, a fairly accurate transducer. These were run with a prelocked inertia reel in order to demonstrate the occurrence of head strikes, even if the restraint system were given the best chance of functioning properly. Two of the tests resulted in belt extensions of 3.5 and 2.0 cm (1.4 and 0.8 in), indicating the belt remained fairly tight and did not extend. Immediate posttest examination of the inertia reel confirmed this assertion. The third test produced an extension of 11 cm (4.3 in), indicating some slippage of the reel or a stretch of the belt must have occurred. Posttest observations indicated the reel, in fact, did lock.

Regardless of the action of the inertia reels or restraint belt, head strikes did occur in tests, as indicated by observed damage to the frangible faces and head acceleration signals. Peak head accelerations in the 85 g to 195 g range and HIC values near 600 produced by all the 35-degree pitch tests were sufficient to cause facial fractures and lacerations and, possibly, irreversible brain damage in actual mishaps.

The Apache ORT tests (Table 2 and Appendix B, Volume II) were all run at the 7 g sled pulse to simulate the early portion of collapse of the landing gear during a crash. All these tests produced head strikes to the ORT regardless of inertia reel configuration. No inertia reel configuration produced consistently better results, as in the TSU test series. Belt extensions remained below 7 cm (2.8 in), except for test LX6212 where the restraint belt extended by 12 cm (4.7 in). Even then, the HIC and peak acceleration of this test were the lowest among this group, despite obvious damage to the frangible face (Figure 8). The highest head linear acceleration for this series was 94 g in test LX6208 and the highest HIC value was 160 in the same test, an indication of the relative "mildness" of head strikes. Nevertheless, all accelerations exceeded facial bone tolerances to fracture. Also, it should be remembered that these tests only simulated crashes where the landing gear did not fully stroke. In crashes that exceed the landing gear sink speed, the 7 g pulse will be followed by a considerably higher magnitude pulse, potentially leading to a secondary ORT strike more severe than the initial strike.

The tests and results discussed so far pertain to the first phase of investigation that did not involve airbags. Clearly, head strikes do occur in realistic impact scenarios, in spite of the use of a properly functioning restraint system.

Discussion of airbag tests

After review of the experiments and the preliminary analysis of Phase 1 data, it was decided the second phase of testing would focus on simulations of "severe" crashes. After all, if the airbag were to be introduced into the AH-1 and AH-64 to supplement the current restraint systems, it would be primarily to prevent injury in the severest of head strikes. All tests with airbags were designed to simulate the 35-degree impact as described in Table 3. Several tests were run with a preinflated airbag to refine the experimental procedures, but they did not produce any reportable results. Although LX6269 was a full-scale airbag test, no manikin transducer signals could be processed. Results from 10 (4 Cobra TSU and 6 Apache ORT) airbag tests are presented in Table 3 and in Appendix C, Volume II.

In all airbag tests, the maninkin's head rebounded after being stopped by the airbag and struck the armored seat. This rebound action is undesirable and would have been reduced with refinement of the airbag deployment or the design of an airbag specifically for the AH-1 or AH-64 cockpit interior. The secondary (rebound) impact produced lower acceleration levels than earlier interaction with the airbag or the underlying support structures. Generally, head contact with the airbag lasted more than 15 ms, so the HIC as an injury assessment tool was not valid. However, the HIC is reported here and was used only for the purpose of comparing one test to another and not to predict injury.

The four Cobra TSU airbag tests (LX6270 through LX6273) produced consistent results. A slight undersetting of amplifier gains caused the head acceleration signals to be clipped, as may be seen in Appendix C, Volume II. As noted in Table 3, true peak head accelerations may be slightly higher than those given for the four TSU tests. The MA-6 in test LX6270 and MA-10 in LX6271 appear to have locked and restricted the belt extensions to under 5.9 cm (2.3 in). Data from tests LX6272 and LX273 were inclusive due to unreliable string potentiometer signals. However, angular pitch accelerations recorded in test LX6273 suggest the reel may have failed to lock.

The remaining six airbag tests (Table 3) were Apache ORT tests. Two of these tests were run at the lower crash pulse severity (7 g, 9 m/s) to simulate the early portion of landing gear collapse during a crash. These were test conditions similar to the seven nonairbag tests (LX6208 thru LX6213, and LX6277) reported in the top half of Table 2. This enabled us to make direct comparisons between the head strike parameters to determine the effects of supplementing the restraint system with an airbag. The last four tests reported in Table 3 have no direct comparison in Table 2. The inertia reels (MA-10) all locked during the ORT tests; however, belt extension appeared to be excessive for all 25 g runs. This is particularly true for LX6280 where the belt extension was 15.8 cm (6.2 in) and head pitch acceleration was 11,440 rad/s^2.

In order to evaluate the effect of the airbag on the head strike, the four Cobra airbag tests were compared to the group of five nonairbag tests discussed earlier and presented in the bottom half of Table 1. The two groups simulated the same 35-degree impact angle, and the severity of the crash pulses essentially were the same. In all runs except LX6273, the inertia reels appeared to lock properly. Aside from minor variations in the test conditions, the primary difference between the two groups was the presence of the airbag. Therefore, any improvement in the response parameters may be reasonably attributed to use of the airbag. A similar comparison was made between the two Apache airbag tests and the seven nonairbag tests.

The small number of tests did not allow formal statistical analysis of the reduction of severity. However, the trend is so clear that some informal characterization of the improvement is possible. To this end, the average values of three parameters were compared: Peak head accelerations (g), the HIC, and the swings of head pitch accelerations (rad/s^2) and velocities (rad/s) at the instant of head strike. In using these parameters, no injury prediction was made. Rather, these parameters were used as indicators to assess the mitigating effects of the airbag on the severity of simulated head strike. The average value is defined simply as the sum of observed values divided by the number of observations. No other statistics were derived because of the small number of observations.

The result of comparisons are presented in Table 7. The average values were computed from results already presented in Tables 1, 2, and 3. The reader may compute additional response measures from the table. Regardless of the response parameter used to compare tests with airbags to those without airbags, the airbag parameter was considerably lower. It is evident airbags are effective in reducing the severity of gunsight head strikes.

Conclusions

This study demonstrated that, during a mishap involving the Cobra or the Apache attack helicopters, the copilot/gunner is at risk for striking his head against the TSU in the Cobra or the ORT in the Apache. This occurs in spite of the proper use and functioning of the standard restraint system. Epidemiological and experimental data suggest the probability of striking the sighting system mainly is dependent on the crash dynamics and, particularly, on the longitudinal velocity at terrain impact. Aircraft roll or yaw at impact may be influential in directing the head trajectory away from the sighting system, and may account for the relatively small percentage of ground impacts resulting in head strikes.

Table 7.

Comparison of means of head response parameters of inertia reel tests with and without airbags.

Test group and improvement due to airbag	Head peak (G)	Head injury criterion	Acceleration pitch swing (rad/s^2)	Velocity pitch swing (rad/s)
Cobra TSU tests[1] without airbag	141	871	12850	70.5
Cobra TSU tests[2] with airbag	47.8	170	3328	22.5
Improvement	66%	80%	74%	68%
Apache ORT tests[3] without airbag	59.9	93	9920	40.5
Apache ORT test[4] with airbag	13.8	31	1300	6.3
Improvement	77%	67%	87%	84%

[1] Group of five tests: LX6203, LX6204, LX6274, LX275, and LX6276.

[2] Group of four tests: LX6270, LX6271, LX6272, and LX6273.

[3] Group of seven tests: LX6208 through LX6213, and LX6277.

[4] Group of two tests: LX6278 and LX6279.

Although it was hypothesized the use of an inertia reel that locked at a lower strap acceleration rate or one that sensed an impact would reduce the severity of head impact, these tests failed to show an advantage in using one of these types of modified reels. Even when runs with technical difficulties in measuring strap extension were excluded, no clear pattern of extension versus crash dynamics or reel type could be discerned. The variability in amounts of extension for similar conditions is either due to stretch of webbing, reel pack down, or variation in the rapidity of reel locking. In any case, these tests suggest the MA-10 dual sensing reel may not provide the solution to excessive upper torso strap extension identified from crash investigations and other sled tests. Clearly, an inertial reel that gives more consistent results should be developed and qualified to anticipate dynamic conditions. Supplementing the improved system with a passive system such as the airbag may be required for optimum protection, particularly in special situations such as the copilot/gunner positions in attack helicopters.

The observations made in this preliminary study clearly show a reduction in head strike severity when an airbag is utilized to supplement current restraint systems. No attempt was made to optimize the airbag design, inflation parameters, or deflation rates. Further studies need to be accomplished to properly design an airbag system for use in Army helicopter cockpits. We believe this concept offers a significant potential for reducing contact injuries in all survivable helicopter crashes and further development of the concept should be given priority.

Recommendations

1. Recommend U.S. Army Aviation Systems Command initiate research and development efforts to develop the airbag concept for use in Army helicopter cockpits to supplement currently available restraint systems.

2. Triservice research efforts should be directed toward investigating the dynamics of inertia reel lock activation. Several reports have documented excessive extension of upper torso straps and cited this as a mechanism of injury in crashes.

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